FUSE Observations towards HD 34078: Detection of highly excited H_2 and HD.

Franck Le Petit[1], Patrick Boissé[2], Guillaume Pineau des Forêts[1], Evelyne Roueff[1], Cécile Gry[3], B-G Andersson[4], Vincent Le Brun[3].

[1] *Observatoire de Paris-Meudon - DAEC - 5 place Jules Janssen, 92195 Meudon.*
[2] *Ecole Normale Supérieure/DEMIRM - France*
[3] *Laboratoire d'astronomie spatiale - France*
[4] *John Hopkins University - USA*

Abstract.   We present FUSE observations of the extincted O9.5 star, HD 34078. The 19 first levels of H_2 are detected (i.e. from J=0 to v=1, J=5) as well as HD in its two first levels. The excitation of H_2 up to J=7 can be explained using a combination of Photon Dominated Region (PDR) and MHD shock models. However, understanding the large amount of H_2 found in higher excitation states seems to require more energetic processes that have yet to be identified.

1   Introduction

FUSE observations towards HD 34078 have been undertaken to study the small scale structure in the spatial distribution of H_2 (see the paper by Boissé et al. in this volume). The first FUSE spectrum turned out to be exceptionally rich since absorptions from the 19 first levels of H_2 have been identified. After a brief presentation of the line of sight, we describe the results obtained for H_2 and HD. A preliminary interpretation of the observed excitation is then performed using Photon Dominated Region (PDR) and magnetohydrodynamic shock models.

2   Description of the line of sight to HD 34078

HD 34078, also known as AE Aurigae, is a O9.5V spectral type star of visual magnitude $m_V = 5.95$, located at 500 pc from the sun. It is a runaway star with a transverse velocity of 100 km·s^{-1} and a radial one of 59 km·s^{-1}. The color excess has been estimated to be $E_{B-V} = 0.52$, corresponding to $A_V = 1.6$ for $R_V = 3.1$. Several observations of HD 34078 have already been performed: HI and CO column densities were measured by Mc Lachlan and Nandy [4] from IUE observations while CH, CN and C_2 have been detected by Federman et al. [2]. The density is estimated to be in the range 200 - 500 cm^{-3}. In addition, CH$^+$ and CH, observed by M. Allen [1], give a Doppler parameter, $b \simeq 3$ km·s^{-1}.
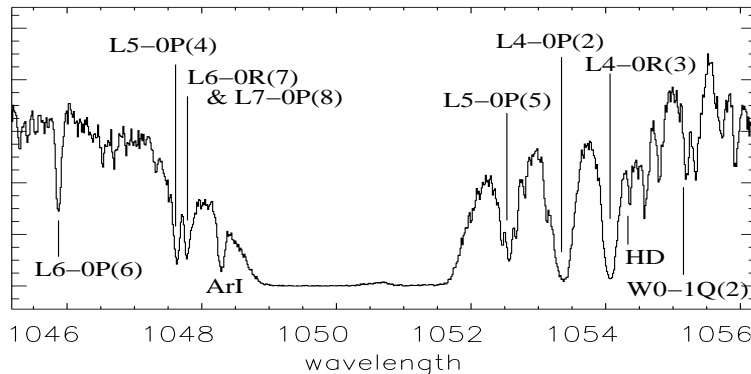
Figure 1: Zoom on a 10 mÅ interval.

3 Observations

The first observation has been performed in january 2000, with a total integration time of 7145s. Data have been processed and calibrated in a standard way using the FUSE pipeline software. In the best portions of the LiF1A spectrum, the S/N ratio is 30 per 15 mÅ pixel; the spectral resolution is about 17000. Fig. 1 displays an extract of the LiF1A spectrum over a 10 Å interval around 1050 Å, showing the numerous absorption lines present in the spectrum. Column densities have been obtained using both a curve of growth analysis and the fitting program "Owens" written by M. Lemoine. Since high resolution CH observations performed in the visible have revealed no marked velocity structure (Federman, private communication), we assumed that there is only one component along the line of sight. Most of the observed lines fall on the flat part of the curve of growth and then poorly constrain the b Doppler parameter. We have thus adopted the value derived by Allen [1] for the lowest levels of H_2 (up to J=4): b=3 km·s^{-1}. However, using ten transitions arising from the J=9 state, we have been able to build a curve of growth for this level, from which we get an upper limit on b(J=9) of 6 km·s^{-1}. For H_2 transitions from J=4 to J=9, we have increased the b parameter from 3 to 5 km·s^{-1}; an uncertainty of 1 km· s^{-1} on the b parameter has been considered. Error bars are given at three sigma, meaning that values outside of the error bars can be excluded. Transitions arising from levels higher that J=9 are optically thin and thus, corresponding column densities are independent on any assumption on b; the same is true for the J=0 and 1 levels for which absorption lines are damped.

Energy (K)	v	j	N (cm^{-2})	Energy (K)	v	j	N (cm^{-2})
0	0	0	3.20×10^{20}	6140.2	1	1	2.10×10^{14}
170.5	0	1	3.20×10^{20}	6471.6	1	2	8.30×10^{13}
509.8	0	2	1.80×10^{19}	6951.6	1	3	1.70×10^{14}
1015.1	0	3	6.20×10^{18}	7197.0	0	9	5.98×10^{14}
1681.7	0	4	7.10×10^{17}	7584.6	1	4	7.00×10^{13}
2503.9	0	5	3.30×10^{17}	8365.3	1	5	1.80×10^{14}
3474.4	0	6	4.00×10^{15}	8677.3	0	10	3.99×10^{13}
4586.4	0	7	2.50×10^{15}	9286.6	1	6	—
5829.8	0	8	6.00×10^{14}	10261.8	0	11	4.00×10^{13}
5987.1	1	0	2.20×10^{13}				

4   Results

We clearly detect absorption lines arising from vibrationally excited H_2 levels up to v=1 and J=5 (8000 K). Other molecules and atoms such as HD, CO, C I, Ar etc... are detected as well. Absorption lines from levels with still higher excitation energies (e.g. v=4, J=2) may also be present but, due to the numerous blends present, it is difficult to establish unambiguously their identification. The table displays the column densities derived for the 19 first energy levels sorted by increasing energy. We derive a total molecular hydrogen column density of:

$$N(H_2) = 6.4 \times 10^{20} cm^{-2}$$

Seven lines from HD J=0 are clearly detected but some of them are blended and it appears difficult to fit all lines with a single N(HD) value. We get the approximate value, N(HD J=0) $\simeq 10^{15}$ cm^{-2}; the accuracy is too low to derive any D/H ratio. The weak HD L7-0R(1) transition arising from the J=1 level is tentatively detected at 1022 Å giving N(HD J=1)) = 1.0 (-0.4 +0.8) $\times 10^{14}$ cm^{-2}. A previous detection of excited HD was obtained using Copernicus by Wright and Morton [8] towards ζ Oph.

5   Discussion

Figure 2 displays the excitation diagram of H_2. The 3 first H_2 levels are consistent with a temperature of 80 K, and a thermal equilibrium ortho-to-para ratio. For higher excited levels, the distribution can be artificially decomposed in two thermal ones with excitation temperatures of 400K (for levels between J=3 and J=7) and 1000K (beyond J=7). Using first the PDR model of Le Bourlot et al. [3] and adopting a density of 500 cm^{-3} (constrained by the observations of Federman et al [2]) together with a radiation field of 2 times the ISRF, it is possible to reproduce the column density of the two first H_2 levels and other molecules, except CH$^+$. However, this model considerably underestimates column densities for levels J $\geq$ 3. A more energetic mechanism
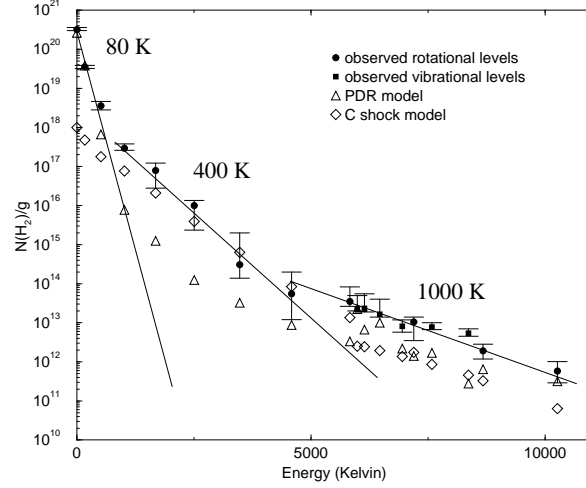
Figure 2: H_2 excitation diagram. For the C shock model considered, a velocity of 25 km·s^{-1} and a magnetic field of 10 μG have been assumed.

is required to account for the latter. We have run several C shock models in the presence of a radiation field (reference [7]). Reasonable agreement is obtained for levels J=3 to J=7 with a shock velocity of 25 km·s^{-1} and a magnetic field of 10 μG. But again, the large amount of H_2 observed at J $\geq$ 8 is well above the prediction of these models. One plausible scenario could involve H_2 located in a bow shock located around HD 34078. Since it is a runaway star, it is now well detached from the cloud where it formed, unlike HD 37903 towards which Meyer et al. [6] found a lot of H_2 excited to high energies by fluorescence. However, due to the large velocity of HD 34078, a strong bow shock is expected to be present at the interface of the stellar wind and of the ambient ISM (Mc Low et al. [5]). Gas trapped in this dense layer might contribute to the observed absorption - a scenario that we need to explore in more details.

References

[1] Allen M. M. 1994, ApJ, 424, 754

[2] Federman S. R. et al. 1994, ApJ, 424, 772

[3] Le Bourlot J., Pineau des Forêts G., Roueff E., Flower D., 1993, A&A 267, 233

[4] McLachlan A., Nandy K. 1984, MNRAS, 207, 355L

[5] Mac Low M.M, Van Buren D. et al. 1991, ApJ 369, 395

[6] Meyer D.M. et al., 2001, ApJ 553, L59

[7] Monteiro T.S., Flower D.R., Pineau des Forêts G., Roueff E. 1988, MNRAS 234, 863

[8] Wright A. L., Morton D. C. 1979, ApJ 227, 483